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Research paper

Lithofacies modeling by multipoint statistics and economic evaluation by NPV volume for the early Cretaceous Wabiskaw Member in Athabasca oilsands area, Canada

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ABSTRACT

The static modeling and dynamic simulation are essential and critical processes in petroleum exploration and development. In this study, lithofacies models for Wabiskaw Member in Athabasca, Canada are generated by multipoint statistics (MPS) and then compared with the models built by sequential indicator simulation (SIS). Three training images (TIs) are selected from modern depositional environments; the Orinoco River Delta estuary, Cobequid bay-Salmon River estuary, and Danube River delta environment. In order to validate lithofacies models, average and variance of similarity in lithofacies are calculated through random and zonal blind-well tests. In random six-blind-well test, similarity average of MPS models is higher than that of SIS model. The Salmon MPS model closely resembles facies pattern of Wabiskaw Member in subsurface. Zonal blind-well tests show that successful lithofacies modeling for transitional depositional setting requires additional or proper zonation information on horizontal variation, vertical proportion, and secondary data.

As Wabiskaw Member is frontier oilsands lease, it is impossible to evaluate the economics from production data or dynamic simulation. In this study, a dynamic steam assisted gravity drainage (SAGD) performance indicator (SPIDER) on the basis of reservoir characteristics is calculated to build 3D reservoir model for the evaluation of the SAGD feasibility in Wabiskaw Member. SPIDER depends on reservoir properties, economic limit of steam-oil ratio, and bitumen price. Reservoir properties like porosity, permeability, and water saturation are measured from 13 cores and calculated from 201 well-logs. Three dimensional volumes of reservoir properties are constructed mostly based on relationships among properties. Finally, net present value (NPV) volume can be built by equation relating NPV and SPIDER. The economic area exceeding criterion of US$ 10,000 is identified, and the ranges of reservoir properties are estimated. NPV-volume-generation workflow from reservoir parameter to static model provides cost- and time- effective method to evaluate the oilsands SAGD project.

1. Introduction

In petroleum exploration and production projects, a recovery factor and revenue are critical because any drilling program is expensive. In order to make a sound decision on the development plan, reservoir static models are built and utilized for dynamic simulations to find the best well location and to reduce a risk. These static models contain reservoir properties like porosity, permeability and saturation which are basic input data for dynamic simulation and are mainly controlled by lithofacies distribution. Lithofacies modeling has commonly been carried out by sequential indicator simulation (SIS) (Deutsch and Journel, 1992; Yao, 2002; Deutsch, 2006) that has some limitations on realistic description of facies connections, especially for those of complex reservoirs (Remy et al., 2009). Object-based Modeling method (OBM) can resolve aforementioned limitation of SIS. For instance, it is appropriate method to simulate model of channel complex (Deutsch and Tran, 2002). However, OBM should need

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pretreatment process and spatial information of depositional element (Pyrcz and Deutsch, 2014). So, the application is considerably limited.

Multipoint statistics (MPS) was developed by Guardiano and Srivastava (1993) to overcome the limitation of SIS and OBM and then Strebelle (2000) suggested the procedure of obtaining probability from training image (TI) using search tree. Recently, MPS has been widely applied for reservoir modeling due to several advantages such as realistic facies distribution, honoring well data, easy conditioning with secondary data (Hashemi et al., 2014; Pyrcz and Deutsch, 2014; de Carbalho et al., 2016) and alternative of variogram modeling (Strebelle, 2002; Caers and Zhang, 2004). The variogram is one of the most important parameters in two-point algorithms. However, it is challenging to build variogram models for each facies, direction, and reservoir properties if few well data are available. As such, this study adopts TI of MPS rather than variogram in order to better represent spatial information. TI generally embodies geological concept for shape and distribution of lithofacies (Strebelle, 2000, 2002). TI is scanned through search window to reproduce a probability tree which is then utilized to build cumulative distribution function for simulation of each cell (Strebelle, 2002). Because the selection of proper TI controls the result of facies modeling, validation of TI is essential for reliable property modeling.

After reservoir property model is validated by facies model, it is utilized for dynamic simulation to establish a development plan such as well location and spacing. For example, steam assisted gravity drainage (SAGD), one of the widely used thermal recovery methods in oilsands reservoirs, uses well pair of steam-injection and oil-production wells. The position of horizontal well-pairs is a critical for oil recovery and can be determined by dynamic simulation. However, the simulation requires various petrophysical properties such as relative permeability, fluid composition, and capillary pressure for reliable prediction. Also, development plan usually requires a huge number of dynamic simulations for sensitivity analysis and optimization scheme. Thus, it can be a huge burden for thermal forward simulation.

To mitigate the simulation time, several researches have reduced the number of simulation using ranking or clustering methods (Lee et al., 2013; Lim et al., 2014). Also, there are studies on a relationship between static parameters and dynamic responses using proxy model or experimental relationship. Shin (2008) proposed economic indicator for SAGD project in a reservoir scale as function of several reservoir parameters such as thickness, porosity, vertical permeability, and oil saturation. In this research, the function, dynamic SAGD performance indicator (SPIDER), is applied to unit cell to identify SAGD sweetspot directly from the property model without reservoir simulation. Therefore, property models based on reliable lithofacies modeling are critical in locating the sweetspot for SAGD project.

The Cretaceous Wabiskaw Member in Western Canadian Sedimentary Basin (WCSB) filled with bitumen but still remains a frontier oilsands formation due to thin reservoir thickness. The accurate assessment to this Member via MPS and SPIDER will provide helpful information to increase economics of SAGD for frontier lease. As input data for geostatistics, hard data are prepared from well logging and TI candidates are chosen from geological setting and structural framework (Keith et al., 1988; Wynne et al., 1994; Wightman et al., 1997; Hein and Cotterill, 2006; Shields and Strobl, 2010). Then, the TIs are evaluated through several blind-well tests. Lithofacies models from MPS are compared with result from SIS. Property model built from the final lithofacies model is utilized for calculation of net present value (NPV) of each cell to obtain sweetspot model. Finally, the most proper MPS lithofacies model is validated and economic area in the frontier oilsands lease can be suggested only based on geological characteristics of reservoir.

2. Methodology

2.1. Workflow

Workflow for lithofacies modeling is designed to build model via either MPS or SIS and to validate model by blind-well tests. Once available data are reviewed, depositional environment and structural framework are interpreted from literature review (Keith et al., 1988; Wynne et al., 1994; Wightman et al., 1997; Hein and Cotterill, 2006; Shields and Strobl, 2010) and well data. In this study, there are 201 well-logs and 13 core descriptions available. Spatial relationships, TI and variogram, are assessed for the two geostatistical methods. After the best lithofacies models are confirmed through random six-blind-well tests and zonal blind-well tests, the reservoir properties set for porosity, permeability, and oil saturation are simulated by sequential Gaussian simulation (SGS) and regression equation. To calculate the monetary value of each cell in the Wabiskaw model, NPV volume is generated from the static models by SPIDER. Finally, sweetspot in the study area and range in reservoir parameters can be determined from NPV volume.

2.2. Geological setting

The Early Cretaceous Manville Group in the Athabasca oilsands region (Fig. 1) mainly consists of the McMurray, Clearwater, and Grand Rapid Formations. The Wabiskaw Member is the basal part of the Clearwater Formation and unconformably overlies the McMurray Formation (Carrigy, 1967; Flach, 1984; Keith et al., 1988; Wightman et al., 1997; Hein and Cotterill, 2006; Benyon et al., 2014). The Member is correlated to the Bluesky Formation in the Peace River area (Shields and Strobl, 2010) and the Glauconitic Sandstone Formation in the Lloydminster area (Central Alberta) (Flach, 1984). The Member has been subdivided into B, C, and D beds based on erosional surface (Wynne et al., 1994; Wightman et al., 1997; AEUB, 2003; Hein and Cotterill, 2006).

The WCSB is the largest sedimentary basin in Canada. During the Aptian to Albian, transgression occurred from the Western Interior Sea (Boreal Sea) which is located on the northern Alberta State. During the Wabiskaw Member was deposited in the WCSB (Wynne et al., 1994; Hein and Cotterill, 2006). The Wabiskaw Member was previously interpreted as the nearshore environment (as a bar deposits) (Carrigy, 1967) and recently revealed as the valley-filled deposits in low relief area (Wynne et al., 1994; Wightman et al., 1997; Hein and Cotterill, 2006) (Fig. 1). The lower bed of the Wabiskaw D beds was interpreted as a valley-filled deposits and shale beds which were interpreted as the shallow marine deposits (Wynne et al., 1994; Hein and Cotterill, 2006).

Shields and Strobl (2010) recently interpreted that the Wabiskaw D beds formed in outer estuary to shallow marine environment during transgression. The study on Kirby North lease, 250 km north from their study area suggests three facies associations (FA) in the Wabiskaw D beds: tidally influenced channel fill (FA1), high energy bay fill (FA2), and marine shoreface sediments (FA3). FA1 and FA2 of the Wabiskaw D Bed are considered to be good reservoir with high porosity, permeability, and high oil saturation (Table 1). In study area, located in the township 76, ranges 6–7 west of the 4th, the Wabiskaw D beds mainly occur in study area only (Jo and Ha, 2013; Shinn et al., 2014), whereas the D sand bed is not deposited in the township 76 and range 6 (Jo and Ha, 2013). Based